Az előállításhoz használt csomagolási anyagoknál először meg kell határozni, hogy veszélyes anyaggal szennyezett, vagy nem szennyezett hulladékról van-e szó, majd ezt követően kerülhet sor a **3.** és **4. ábrán** látható hulladékkezelési módozatok egyikének megválasztására.

Cikksorozatunkat a gépek, járművek üzemeltetése és karbantartása során keletkező és egyéb hulladékok kezelésére és hasznosítására kidolgozott modellek, valamint a végső következtetések ismertetésével folytatjuk.

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Application of the second order Fourier transformation on the density function of sugi trees

Levente Csoka, Jianjun Zhu, Katsuhiko Takata [❖]

A másodrendű Fourier transzformáció alkalmazása a sugi faanyag sűrűségfüggvényére

A juvenilis fa és az érett faanyag elkülönítése a fatesten belül hosszadalmas és igen fárasztó anatómiai vizsgálatokat igényel, és a végeredmény sok esetben nem egyértelmű. A szerzők olyan eljárást írnak le, melynek során a Fourier transzformáció kétszeri alkalmazásával a faanyag radiális irányban felvett sűrűségfüggvényéből egyszerűen és nagy pontossággal meghatározható a juvenilis és az érett faanyag határvonala. A módszer alkalmazásával meghatározott határvonal sugi faanyag esetén figyelemreméltóan jó korrelációt mutatott a tracheidák hosszúságának mérésén alapuló, nagy pontosságúnak tartott szegmentált regressziós modell által szolgáltatott értékekkel.

Key words: Juvenile wood, X-ray densitometry, Density function, Fourier transformation

Abstract

The juvenile wood has features that distinguish it from the older, more mature wood of the bole. Juvenile wood is an important wood quality attribute because, depending on species, it can have lower density, has shorter tracheids, thin-walled cells, larger fibril angle, and high – more than 10% – lignin and hemicellulose content and slightly lower cellulose content than those of mature wood (Zobel and van Buijtenen 1989, Zobel and Sprague 1998). Wood juvenility can be established by examining a number of different physical or chemical properties. Juvenile wood is not desirable for solid wood products because of warpage during drying and low strength properties, and for producing high stiffness veneer, either (Zhu et al. 2004).

Fourier transformation is an extremely useful mathematical tool used in the quantitative analysis of many physical processes. Fourier transformation can be represented as a series of sine and cosine functions. The main purpose of the experimental work described in this report was to develop a new method to determine the demarcation between juvenile and mature wood by means of Fourier analysis of the density distribution curves.

Introduction

An analysis is justified only if it leads closer to an understanding of the system. The

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value of theoretical models consist in their ability to unlock hitherto unintelligible relationships, thereby enabling us to penetrate deeper into the secrets of wood formation. It is widely accepted that, under a given set of conditions, living woods endeavor for an optimal cambial activity and compensate environmental effects. In our analysis, we treat the density function as a mathematical expression of the final formation of the growing wood.

The significance of the density function goes beyond its economic importance. The density function shows the annual increment of wood in terms of volume (as expressed by annual ring width) and mass substance. It also indicates the amount of different chemical constituents. For each successive peak of the density function we try to explain how this peak mirrors the natural logic of growth. Fourier analysis is a powerful tool for interpreting the meaning of this function, because it reflects the complex interaction between annual ring width and density variation.

The density function is a result of the superposition of many different environmental factors, such as, rainfall, soil and site conditions, temperature, etc. We may assume that each of these factors cause periodic changes in density along the radius. If we can identify each of these effects, we shall have an ultimate understanding of the nature of wood formation that goes beyond simple annual ring analysis. Above all, it gives a true image not only of the structure, but also the essence of wood material itself.

In this study the authors would like to assess what information the Fourier analysis can provide in terms of wood properties.

Wood juvenility

Timber is a biosynthetic end product and, therefore, the making of wood is a function of both gene expression and the catalytic rates of structural enzymes. Thus, to achieve a full understanding of wood formation, each component of the full set of intrinsic processes essential for diameter growth (i.e. chemical reactions and physical changes) must be known and information is necessary on how each one of those components is affected by other processes (Savidge et al. 2000).

The younger juvenile wood produced in the crown has features which distinguish it from the older, more mature wood of the bole (Zobel and Sprague, 1998). Variations within a species are caused by genetic differences and regional differences in growth rate. Differences also occur between the juvenile and mature wood within single trees, and between the earlywood (springwood) and latewood (summerwood) within each annual growth ring.

Juvenile wood occupies the center of a tree stem, varying from 5 to 20 growth rings in size, and the transition from juvenile to mature wood is gradual. This juvenile wood core extends throughout the full tree height, to the uppermost tip. (Myers et al. 1997).

Juvenile wood is unsuitable for many applications and has great adverse economic impact. Juvenile wood is not desirable for solid wood products because of warpage during drying and low strength properties and critical factors in producing high stiffness veneer (Willits et al. 1997). In addition, in the pulp and paper industry, juvenile wood has higher tear index, tensile index, zero-span tensile index, and compression strength than mature wood. For the same chemical pulping conditions, pulp yield for juvenile wood is about 25 percent less than pulp yield for mature wood (Myers et al. 1997).

In our days, Fourier transformation is one of the most advanced processes to analyze vibration. Knowledge of the mechanism of the Fourier transformation gives the possibility to analyze special functions. In this study the authors suggested that the density curves after scanning are similar to vibration functions. Regardless the frequency, we can divide these curves into Fourier series. Every curve has a particular spectrum after transformation.

The use of microfibril angle and tracheid length in determining the boundary line between juvenile and mature wood has received most attention during recent years. Studies in this area have focused on the segmented regression method and the variation in tracheid length by ring number.

Another important factor to consider in Fourier analysis is the need for cost effective and less time-consuming analyses to make the examination of large samples possible. This includes the whole process from sampling through sample preparation and measurements to the analysis of measurement data. It is also important to have high precision in measurements to decrease the number of measurements necessary.

This report is the first paper concerning the Fourier-analysis-assisted assessment of the boundary line between juvenile and mature wood.

The Fourier analysis

Fourier transforms are classical tools in signal processing where the measurement of spectra is used to characterize time-dependent processes. Consequently, there are many ways of transforming signals and image data into alternative representations that are more amenable for certain types of analysis.

Fourier Transformation of One Dimensional Density Functions

When analysing signals, pictures and systems, the Fourier representation plays an extremely important role. A Fourier transform is an operation which converts data from time functions to frequency functions. In our case, we converted the independent variable from distance to incidence, using Fourier transformation.

If $x(s)$ – the density function – is a one-dimensional continuous function (i.e. an integral value can be found) and the density varies along the distance, then the Fourier-transformed function F is defined as follows:

$$F\{x(s)\} = X(\nu), \qquad [1]$$

where the F operator converts density as a function of distance, *x(s)* into a function of incidence, *X(ν)*.

The F operator means in mathematical notation:

$$X(\nu) = \sum_{n=0}^{N-1} f(n \cdot \Delta l) e^{-i(2\pi\nu)(n\cdot\Delta l)}, \; \nu = k \cdot \Delta f, \qquad [2]$$

for $k = 0,1,2,...,N-1$. (Variables are defined later.)

The Fourier Transformation changes the dimension of the independent variable according to the input signals or pictures. In most cases, the new function provided by the Fourier Transformation gives valuable information. In order to achieve further results of the nature of signal or picture analysis the authors have investigated the second order Fourier Transform (FT) of the original signals. We call this *second order* because we performed the same mathematical equation to gain a second spectrum. The second order FT means, that we repeat the original transformation again, in the same direction as in the first case (i.e. not an inverse transformation.) The amplitude spectrum has been the prime data, same as in Inverse Fourier Transformation, but the sign of the exponent remains negative.

The second order FT shows new results. Most common signal and image transformation procedures use the inverse transformation to improve the original function. The second FT shows new information that has been retained from the first FT spectrum, on the original (distance) scale.

The Second Fourier transform is defined as:

$$F\{X(\nu)\} = x'(s) \qquad [3]$$

The first spectrum is used for analyzing the frequency structure of continuous signals and the second spectrum for analyzing the complex effect of those waves. The latter spectrum shows the interaction of waves.

Properties of the spectra

The relevant variables are defined as:

- N – number of discrete samples taken (from 14000 to 40000, depending on the age of the sample)
- L – length of the specimen [mm]
- Δl – distance increment between samples $\Delta l = L/N$ $[mm]$ (0.015 mm in every case)
- Δf – frequency increment for the output $\Delta f = 1/L$ $[1/mm]$
- f_s – sampling frequency $f_s = 1/\Delta l$ $[1/mm]$

Spectrum nr. 1

The input data are discrete values of the density function (N). The output FT is a series of complex numbers, one corresponding to each discrete density point. The FT curve consists of the modulus (absolute value) of the complex numbers obtained by the transformation. This spectrum called *frequency* or *amplitude* spectrum. The dimension of the vertical axis is the same as that of the raw data, but the horizontal axis is converted to incidence. The domain is 0 to $f_s/2$, because of the Nyquist criterion and the interval between frequency points is determined as $\Delta f = 1/L$. The spectra shown in this paper has been generated and plotted using *DPlot* software.

Spectrum nr. 2

The input data are *frequency spectrum* values (N_2). The output is a series of complex numbers amplitude which were obtained from the *frequency spectrum*. The second order FT plays an important role, and is defined only in the case of compound functions. A pure *sine* or *cosine* function results in a simple exponentially decreasing pattern. Curves are more interesting when using compound functions. These spectra correctly show spikes at certain points. The physical meaning of these peaks is that at these locations in the original complex function, the superposition of two or more periodic curves results in an axis intersection. However, this study does not aim to give further mathematical considerations; these will be discussed in another article later.

Materials and methods

Sample preparation

Seventeen selected trees, from plantations in Akita Prefecture, Japan, were investigated. The name of the tree is sugi (*Cryptomeria japonica D. Don*). The trees were harvested at different ages between 28 and 214 years. Tracheid lengths and annual ring structure were determined from those samples. Results have been partly reported while some results are currently under publication (Zhu et al. 2004, Yamashita et al. 2000.)

X-ray densitometry

Bark-to-bark radial strips of 5 mm thickness were prepared from the air-dried blocks cut from the sample disks. After conditioning at 20 ^{o}C and 65% RH, without warm water extraction, strips were X-rayed onto film using 340 seconds of irradiation time. Current intensity and voltage were 14 mA and 17 kV, respectively. The distance between the X-ray source and the specimen was 250 cm. The developed films (**Figure 1**) were scanned with a densitometer (JL Automation 3CS-PC) to obtain density measurements across the growth rings.

The growth ring parameters of ring width (RW), minimum and maximum density within a ring (D_{min} and D_{max}, respectively) and average density within a ring (RD) were determined for each growth ring by a special computer software. The latewood is categorized according to Mork's definition, as a region of the ring where the radial cell lumens are equal to, or smaller than, twice the thickness of radial double cell walls of adjacent tracheids (Evans 1999). A threshold density of 0.55 g/cm^3 was used as the boundary between earlywood and latewood (Koizumi et al. 2003).

The development of x-ray-based density analysis should be focused not only on growth rings but also on the structures within the ring. According to Barbour *et al*. (1997), it should be possible to detect structures within the ring that are produced during the earlywood or latewood formation. In addition, it allows accurate measurement of density distribution within samples, and can provide detailed information on the distribution of chemical elements (Evans 1999).

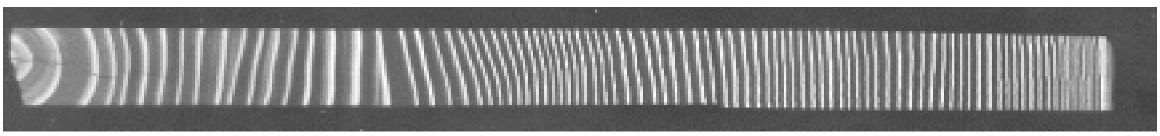

Figure 1 – X-ray image of sample nr. 9

Density function

The density function is a 1 dimensional continuous signal, which describes the density distribution from the pith of a wood sample to the bark (**Figure 2**). Wood density is related to ring growth and its variation has been represented on a density function (**Figure 3**). To gain any new information about the relationship between radial distance and density, we should investigate these factors together, otherwise these attributes show as independent properties. Densitometer provided the distance in millimeters. Distinctive density function characteristics are apparent near the pith and bark.

Difficulties can arise in determining the sampling range (L) due to differences in cambial activity. The first one to four rings of tree development are disregarded, according to principles that we will discuss in a later article. Accurate determination of this sampling domain is one of the key requirements to improve our understanding of wood formation. Different ranges yielded widely varying estimates of juvenile and mature wood within individual trees. As results show, correct outcome is achievable only by using the appropriate sampling range.

Results and discussion

The properties of the recorded spectra are summarized in **Table 1**. In the course of the second Fourier transformation of the density function, the location of the highest peak is especially important. In each of our measurements, the location of that peak corresponded to the transition point between juvenile and mature wood, as defined by the segmented regression method mentioned earlier. Beside this peak, there are several different spikes that have other meanings, although defining them is very difficult due to the complexity of wood formation (**Figure 4**).

The results of the experiments are given in **Table 2**. The third and fourth columns contain the annual ring numbers where the transition occurred, and its distance from the pith, respectively, as defined by the segmented regression model based on the tracheid length. The fifth and sixth columns contain the same

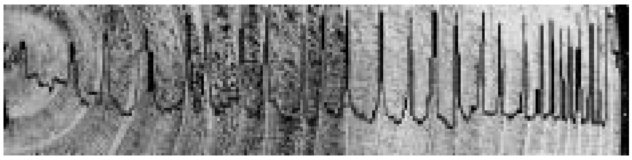

Figure 2 – Density distribution of a sample

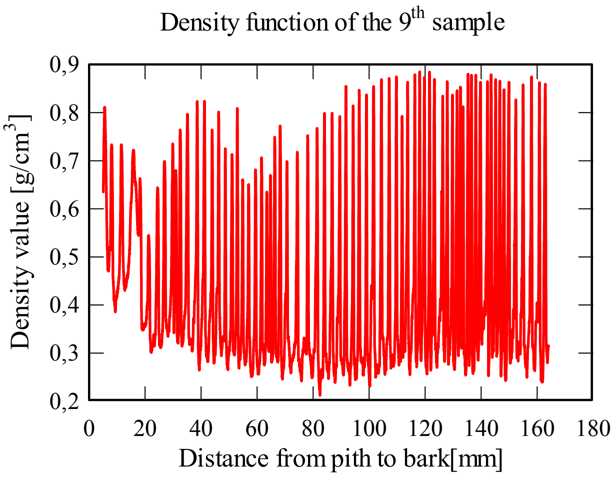

Figure 3 – Density distribution of the 9th sample

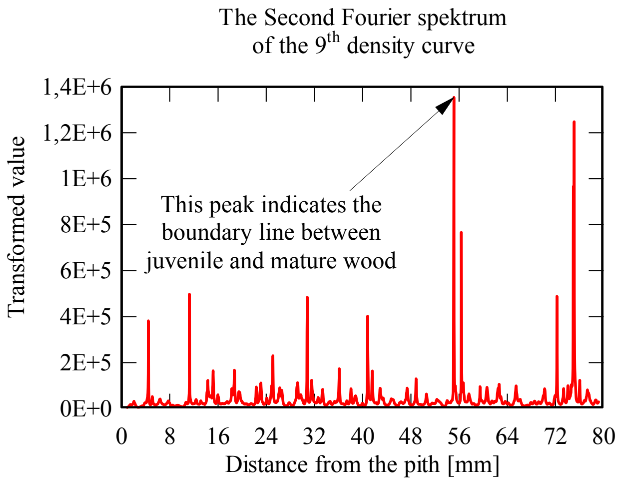

Figure 4 – 2nd Fourier spectrum of density distribution of sample nr. 9.

respective values as provided by the second Fourier spectrum of the density function. The second order Fourier Transforms were generated from the original, unmodified density curves of the samples. Application of the Fourier transformation resulted in the same distances from the pith as those determined by the segmented regression procedure. A few samples showed a difference of one annual ring, but this discrepancy is insignificant. Substantial differences – 10-25 annual rings – appear in

Table 1 – Relevant variables for the 1st and 2nd Fourier spectra, compared to the original properties of the density function

Properties	Density function	Spectrum nr. 1	Spectrum nr. 2
Length of the x axis	$L \quad [mm]$	$f_s / 2 = 33.3\dot{3} \quad [1/mm]$	$L/2 \quad [mm]$
increment between samples	$\Delta l = L/N = 0.015\,[mm]$	$\Delta l = L_1/N_1$	$\Delta l = L_2/N_2$
number of samples	N	$N/2$	$N/4$

Table 2 – Boundary line position between juvenile and mature wood as determined by measuring tracheid length and applying of Fourier analysis

Sample	Tree age [year]	Segmented regression model		Fourier analysis	
		Annual ring number	Distance from pith [mm]	Annual ring number	Distance from pith [mm]
C1	28	21-22	96-98	21-22	97.65
C29	28	21-22	83-86	20-21	81.8
C33	30	21-22	110-113	21-22	110
C36	29	20-21	100-105	19-20	95.82
C39	29	18-19	94-99	18-19	98.68
T6	75	21-22	71-74	21-22	73.15
T8	71	24-25	61-64	24-25	63.43
T9	73	22-23	54-56	22-23	55.14
T10	73	16-17	40-43	17-18	44.03
IV1	93	10-11	36-41	10-11	40.30
IV2	94	14-15	40-43	15-16	44.80
IV3	95	14-15	59-64	15-16	66.25
VI1	100	14-15	58-62	13-14	56.20
VI2	94	15-16	44-51	16-17	55.10
VI3	102	17-18	89-96	16-17	87.32
VI4	96	16-17	44-57	17-18	57.80
NT 11C	214	22-23	97-101	22-23	100.75

the location of the juvenile/mature wood transition among individual trees. Both methods indicated these differences, which confirms that their concurrence is not by chance.

Further analysis of the spectra revealed a definite pattern in the occurance of the other peaks that is probably related to the annual growth. Their magnitude and distance from the pith show regularity. A hypothesis of cambial activity could be proposed. Changes in xylem characteristics caused by periodic annual radial growth fluctuations due to the climatic and soil conditions may account for the emergence of these peaks.

Conclusions

The main objective of this study was to compare the performance of juvenile and mature sugi trees. The implications based on the second order Fourier analysis are far-reaching. These findings should be considered as preliminary results. Density spectra from X-ray imaging creates unique conditions which provides new information in non-destructive testing of wood. Until recently, testing for wood juvenility required wood samples to be milled, dissolved in acids and painstakingly analyzed for certain anatomical features. The new method proposed in this paper opens new possibilities in the analysis of wood formation.

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A faanyag és fémionok kölcsönhatása. III. rész: a fény hatása a krómionnal kezelt fafelületek abszorpciós spektrumára

Stipta József, Németh Károly, Molnárné Hamvas Lívia ❖

Interaction of the wood surface with metal ions. Part 3: The effect of light on chromium impregnated wood surface

UV-light-caused changes of untreated and chromium impregnated wood surface were investigated by absorption spectrophotometric methods. The properties of indifferent silicagel and cellulose layers were compared to the behaviour of poplar and black locust surface. Chromic-ion-impregnation had no significant effect on the absorption spectra of these layers. On the other hand, hexavalent chromium was reduced and the UV-light caused irreversible wood degradation. Surface treatment caused considerable modification in black locust.

Key words: UV-light, Impregnated wood, Chromium, Absorption spectra

Bevezetés

Az ipari gyakorlat a faanyagok fény elleni védelmére leggyakrabban a króm-sókkal történő kezelést ajánlja (Rowell 1984). Korábbi vizsgálataink során megállapítottuk, hogy a krómion oxidáltságának fokától függően eltérő módon hat a faanyag színére, illetve látható és ultraibolya spektrumára (Molnárné és tsai 2004).

A szín- és a fényabszorpció alakulására a fafaj, illetve annak kémiai összetétele is jelentős befolyással bír. Fényhatás a kezelt és kezeletlen faanyag színét jellegzetesen változtatja meg. A színváltoztatásban mind a faanyag, mind a krómion jellege jelentős szerepet játszik (Stipta és tsai 2002). A lejátszódó folyamatok pontosabb mechanizmusáról a felületekről készített infravörös és ultraibolya spektrumok adhatnak felvilágosítást (Németh és Stipta 2002).

Vizsgálati módszerek, eszközök

A vizsgálatokat inert felületen (szilikagél), tiszta cellulózhordozón (Wattmann szűrőpapír), nyár faanyagon, mint gyakorlatilag extraktmentes famintán, valamint a jelentősebb

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